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BIBLIOGRAPHY OF CORROSION AND EROSION-CORROSION IN COAL WASHING PLANTS

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BIBLIOGRAPHY OF CORROSION AND EROSION-CORROSION IN COAL PREPARATION PLANTS

by

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INTRODUCTION

The national and international demand for coal as a source of energy has been steadily increasing during the past few years. The Canadian coal industry has been expanding rapidly in both the eastern and western regions to supply coal to these markets. In a paper "Coal" published in Canadian Mining Journal, February, 1978, J.A. Aylsworth stated that "Canadian coal production rose to approximately 28.4 million t in 1977, an increase over the 25.5 million t produced in 1976". Aylsworth is a marketing and transportation economist with the Coal Division of E.M.R.'s Energy Policy Sector.

Raw coal has been recognized as an abrasive material ever since miners started mining coal. They observed that metal tools and equipment used to remove the coal from mines and to process it soon became worn and required repair or replacement. The frequency of equipment replacement increased as production expanded. The severity of the wear was dependent on such factors as the abrasiveness of the raw coal, the water present in the coal and the mine, and the chloride, sulphate and oxygen content of this water. The introduction of wet mining and processing to meet

health, fire, environment and consumer standards substantially increased the number and severity of these wear (erosion-corrosion) problems. Although numerous published papers deal with various phases of coal preparation, relatively few authors mention wear even though it is classed as a major problem by others^{1,2}.

Hardgrove¹ reported that maintenance costs entailed by the wear of grinding elements is often a more important variable than the cost of the power required to pulverize different coals. In a verbal communication, Dr. J. Visman, retired head of EMR's Western Research Laboratory, stated that there were numerous unsolved erosion-corrosion problems in Canadian coal washing plants that were impeding production.

In view of these facts it was decided that a survey of corrosion and erosion-corrosion problems in coal preparation plants should be undertaken. A survey of this type would enable CANMET to recommend corrosion control methods and more resistant materials to the industry and to initiate research and development for problems requiring new or improved technology. Firsthand information was obtained by making field trips to coal washing plants in western and eastern Canada. The observations made during the trips (see Mineral Sciences Laboratories Reports ERP/MSL 77-148 (FT) and 77-312 (FT)) confirm that wear (erosion-corrosion) causes premature failure of equipment which severely impedes production. Background information about corrosion and erosion-corrosion problems and materials selection in coal preparation plants has been obtained by surveying literature. The information obtained has been compiled in this bibliography.

The bibliography starts with a reference to a paper by Hardgrove in 1937 and then lists other authors by date of publication in each subsequent year. This system has been adopted because some authors discuss the wear and tear of two or more pieces of equipment thus making it difficult to arrange the references in accordance with the various process steps. Most of the references are accompanied with a brief statement of the information each paper contained about wear. The references were obtained from foreign and domestic research reports, journal articles, conference proceedings and books. A bibliography "Coal Processing, Production, and Properties", TID-3349-SIP 1 and 2 compiled by the United States Energy Research and Development Administration, Technical Information Center is worthy of particular note because it provided the key information for the location of many of the references cited in this report.

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1. Hardgrove, R.M. "Grindability of coal from the producers viewpoint". Proceedings of the Seventeenth Fuel Eng. Conf., Fuel Eng. Div., Appalachian Coals Inc., Jan. 11, 1937.
2. Craig, O. "Selection of pulverized coal equipment". Proceedings of the Twenty-Second Fuel Eng. Conf., Fuel Eng. Div., Appalachian Coals Inc., Feb. 8, 1938.

Craig reports that one coal may cause pulverizer parts to wear several times faster than another.

3. Frick, C.H. "Grinding of anthracite for pulverized fuel". Amer. Inst. of Min. and Metall. Eng., Tech. Pub. 2061, 1-8; Aug. 1946.

Frick reported a 50 percent reduction in wear when Ni-hard balls were used in place of forged steel balls to grind coal at the Pine Grove plant in Pennsylvania.

4. Zelders, H.G. "La corrosion superficielle dans le circuit de lavage des charbonnages des mines de l'état Néerlandais". Métaux et Corros., 25:65-76: No 283; 1949.

Zelders concludes from his work that:

- a) Under preparation plant circumstances, corrosion is proportional to the oxygen concentration and to the electric conductivity of the water (pH was practically constant in the mine waters considered).
 - b) The corrosion-retarding oxide layer on the metal surface, which is formed in clear water, is taken away by the solid particles, with the result, that loss of material due to corrosion is enormously increased.
 - c) Direct attack of the metal by the solid particles (erosion) is only of minor importance here.
5. Yancey, H.F., Greer, M.R. and Price, J.D. "An investigation of the abrasiveness of coal and its associated impurities". Trans. AIME, Min. Eng., 3:262-268; 1951.

These investigators developed a laboratory procedure for estimating the abrasiveness of coal. A set of wear blades is revolved for a fixed number of revolutions in a charge of coal. The loss in weight sustained by the blades is taken as a measure of the abrasiveness of the coal. The test revealed that the impurities in coal are considerably more abrasive than the coal. The presence of even a small amount of excess moisture increased abrasiveness significantly.

The researchers thought that the moisture toughened the coal and that corrosion was unlikely. (See Yancey's list of references for other methods of abrasive tests).

6. Harper, W.G. "General features of the design of run-of-mine coal preparation plant". Symposium on Coal Preparation, 25-28 November, 1952, University of Leeds Dept. of Mining, 113-146.

The author stated that "special consideration must be given to the layout and accessibility of machines known to be subject to wear and tear such as screens, crushers, centrifuges and vacuum filters. The design of troughs and chutes in such a way as to minimize maintenance is a problem; the choice lies between lining with mild steel plates, rubber, glass or tiles or alternatively, increasing the thickness of the plate to 1/2" or even 3/4" to be replaced after say five or ten years of operation.

7. Krijgsman, C. "The Dutch State Mines cyclone washer". Symposium on Coal Preparation, 25-28 November, 1952, University of Leeds Dept. of Mining, 83-112.

The author thoroughly describes the working of a hydro-cyclone as a washer in coal preparation plants but does not mention wear. In reply to a question about rate of wear of the cyclones and the development of renewable linings, he stated that the Dorr Company in the U.S.A. had made considerable progress in this area and were using a very wear-resistant carborundum lining.

8. Hoffmann, E. "Treatment of small coal in high, medium and low-pressure cyclones". Second International Coal Preparation Congress, Essen, 20-25 September, 1954, paper A III 6.

The heavy wear and tear on equipment was causing more concern than the high loss of magnetite. A major factor of wear was the erosion of the cyclone. The life of a high pressure cyclone was given as 3 to 4 months. Medium pressure cyclones were expected to give considerably more service but contrary to expectation, after three months the cylindrical section (cast iron) at the inlet was worn through. Details of the failure are described. Malleable hard iron was expected to last 5 to 6 months.

Rotors and housings of pumps were worn out in 850 hours. Those made of chrome-nickel steel gave approximately the same service as those made of white malleable cast iron which were much cheaper.

In the discussion of the paper, Dr. F.W. Mayer (WEDAG) stated that WEDAG, the supplier of the cyclone washing plant, had thoroughly investigated the wear and tear problem. The results revealed that a special type of chilled cast iron was markedly superior to other materials such as porcelain, glass, normal cast iron or gray cast iron. The wear resistance of the chilled cast iron was further improved by a new type of casting process developed by a Dr. Cloos Sinn. Dr. C. Krijgsman stated that a good white cast iron treated in the right way gave longer service. He also said that Wilfley pumps gave good service for 3000 hours.

9. Hall, D.A., Hook, W. and Myers, E.M. "Disposal and use of waste ammonia liquor in froth flotation of coal". Second International Coal Preparation Congress, Essen, 20-25 September, 1954, paper A III 6.

These authors describe the corrosion problems encountered when waste ammonia liquors are used to float coal in flotation cells. Monel filter cloths which had lasted for 3 years, failed in six months. Polyvinyl chloride type plastic cloth was used in place of monel. However, the mechanical strength of the plastic was still being assessed. Pump impellers which were subjected to fairly rapid erosion (6 month life) have been found to have a short life (2-3 months) since the liquor was added to the circuit. Chutes and launders also showed signs of enhanced erosion.

10. Lewis, J.L., "Recent developments in the treatment and handling of fine coal". Second International Coal Preparation Congress, Essen, 20-25 September, 1954, paper A IV 6.

Under "wear and tear" this author refers to stainless steel cloths on Sherwin screens failing in 4 1/2 months. Monel wire cloth on the filter drums lasted 18 months which was longer than originally anticipated. Linatex diaphragms on sludge pumps lasted 12 weeks. The impellers on the flotation cells, which were constructed of a very hard iron, were showing very little wear.

11. Meerman, P.G. "The quality of the water, used in coal preparation processes". Second International Coal Preparation Congress, Essen, 20-25 September, 1954, paper A IV 13.

This author refers to the work of Zelders (reference 4 in this paper) to explain his corrosion problems. Sodium polymetaphosphate was used to retard calcium carbonate crystallization in pipes and on screens. Deposits of calcium carbonate were removed by treating the filter feed with sulphuric acid under strict control of pH and S.I. A pH of 7.45 was used.

12. Meyer, M. "Primary classification of raw coal 80 mm - 0 by wet-screening in the washeries of the Saar Mines". Second International Coal Preparation Congress, Essen, 20-25 September, 1954, paper AV 3.

Wet-screening increased wear and tear on the screen frames and reduced the life of screen plates by about a half.

13. Fontein, F.J. "The D.S.M. sieve bend, new tool for wet-screening of fine sizes, application in coal washeries". Second International Coal Preparation Congress, Essen, 20-25 September, 1954, paper A V 4.

The author describes the wear that takes place on the bars of the screen surface and points out that worn bars produce finer screening and lower capacity. This effect is reduced by rotating the screens so that the feed passes over the bars in the opposite direction. This procedure maintains the thickness of the thin layers spouting through the slots sufficiently constant and hence the fineness of the screening will be equally constant. The bar sieves used in the sieve bend finally show too much wear, the slots become too wide and the separation gets too coarse, then the screen surface has to be renewed.

14. Brunard, J., Edeline, F., Lieben, P. and Liegeois, R. "The clarification of water from washing and screening plants". Third International Coal Preparation Conference, Liege, 1958, paper E 14.

These authors point out that waters charged with solids cause wear, chiefly of pumps and the apices of cyclones, by erosion. The active element in a Campine pit water was the Cl^- ion whereas the SO_4^{--} ion had no effect on corrosion. Results obtained with a rotary corrosion metre are given.

15. Bakker, J.C. "Some observations on the inspection and maintenance of resonance screens in coal washeries". Third International Coal Preparation Conference, Liege, 1958, paper F 4.

Protection of screen casings against corrosion was achieved by thoroughly cleaning all metal surface to bare metal and then applying a suitable paint system. Top coats of polyisocyanate or epoxy resin paints have given good results (3 to 3 1/2 years).

16. Leeman, J.N.J., Heynen, J.Th. "The use of polyurethane as a wear resistant material under wet conditions in coal washeries". Third International Coal Preparation Conference, Liege, 1958, paper F 10.

Some applications of "Vulkollan" a polyurethane plastic, at spots of intense wear in coal washing plants are described. The product is compared with other wear-resistant materials. In most cases, where wear was caused by suspended abrasive solids, performance of Vulkollan was very good and only when hot water and/or cavitation came into play (pump liner) was the plastic unsuitable. Vulkollan is supplied as sheet material.

17. Evans, W.S. and Wiktorek, S. "Corrosion in coal mines and its prevention". Australasian Corrosion Engineering, 7-16; Sept. 1960.

Corrosion in coal mines reduces the service life of items such as coal winning and haulage equipment and increases maintenance costs. The effect of corrosion on equipment used for the transport of men and materials is partly responsible for the stringent safety requirements set on these items. Hence the careful selection of materials of construction, and the application of corrosion control measures becomes an important factor in the industry.

This paper outlines the principal causes of corrosion of mine equipment, and the methods adopted to minimize its effects. The results of experience and service trials in the Southern and Northern Coal fields of N.S.W. are given. Various materials are mentioned for specific locations.

18. Hayter, W. "Corrosion-erosion problems at a coal cleaning plant". Australasian Corrosion Engineering, 17-24; Sept. 1960.

In this paper the author discusses the corrosion-erosion factors associated with each stage of cleaning and the steps taken to overcome these problems in the coal cleaning plant at the Newcastle Works of the B.H.P. Co. Ltd. Re-design of equipment, the use of protective linings and the proper selection of new materials have been the main factors in greatly reducing the high cost of repairs and maintenance. The abrasive slurries contained on an average 2200-2600 ppm chlorides as NaCl and 110-295 ppm sulphates.

19. Parish, B.M. "Mechanisms and methods of measurement of metallic wear". The B.C.U.R.A. Bulletin, 27:6:197-210; 1963.

This paper is a review of literature on wear and includes 79 references. Parish refers to corrosion as one of the four major wear mechanisms. He concludes from the work reviewed that all the four principal wear processes (adhesion, abrasion, corrosion and fatigue) may be expected to be found in coal pulverisers, but that sufficient data to judge their relative severity in a given situation do not exist. The paper shows that several different techniques exist for the measurement of wear rates.

20. Schneider, W. "Kunststoffe in der Steinkohlenaufbereitung". Glückauf, 101:666-670; Heft 11, 1965. (in German).

Translation not available.

21. Hiorns, F.J. and Parish, B.M. "Investigations of the wear of coal pulverizers: Part I. General considerations and Description of a laboratory method". J. Inst. of Fuel, 3:126-133; 1966.

The authors describe a laboratory roll crusher apparatus with a radioactive insert for measuring wear. The wear debris from the rolls was concentrated by ashing the coal and then compressing the ash. The radioactivity of the ash is then measured. Corrosion of the roll surfaces during idle periods was shown to be a factor in determining the wear rates.

22. Leeman, J.N.J. "Wear limitation in coal preparation plants". Mining Congress J., 4:78-83; 1967.

This author was chief development engineer for coal and mineral preparation plants for Dutch State Mines (DSM). He stated that "Much of the equipment in washeries is subject to abrasive wear and periodically needs replacing or repairing". The paper deals with the measures taken by D.S.M. to lengthen the life of certain items of coal preparation equipment and to reduce maintenance costs. Hammer crushers, conveyor chain components, pumps, launders, pipes, pipe bends and thermal dryers are discussed and methods of reducing wear are given. In those instances where initial costs are higher than would be experienced with the cheaper constructions, the added expenditure can be made good within a short time.

23. Yancey, H.F. and Greer, M.R. "Coal Preparation". Am. Inst. of Mining, Metallurgical and Petroleum Engineers, Inc., Ed. by Leonard, J.W. and Mitchell, D.R., 3rd edition, 1, 33 to 35, 1968.

These authors refer to their previous work (reference 2 this paper) in which they developed a method of estimating the abrasiveness of coal and impurities. Results are determined on moisture free basis.

24. Fedorchenko, V.E., Zarubinskii, M.A. and Andreev, V.V. "Increasing the wear resistance of parts of slurry pumps". Tekhnika i Tekhnologiya Obogashcheniya Uglei (USSR) 5:280-287; 1968. V. Mesenzeff (translator); available from Foreign Technology Div. Wright-Patterson Air Force Base, Ohio, U.S.A.

Laboratory and implant tests conducted at beneficiation plants of the Donbas confirmed that the parts of slurry pumps cast from an Ichkh 28N2 alloy containing C-2.4, Si-0.89, Mn-0.51, Cr-34.5, Ni-3.16 and P-0.08 (Brinell hardness 444-477) exhibited a higher wear resistance than

parts made of five other alloys tested. The service life of parts made of the Ichkh 28N2 alloy was 15 times longer than that of parts made of grade Schl5-32 gray cast iron. It is recommended that precision casting be employed to eliminate mech. treatment (author).

25. Lucas, J.R., Maneval, D.R. and Foreman, W.E. "Coal Preparation". Am. Inst. of Mining, Metallurgical and Petroleum Engineers, Inc., Ed. by Leonard, J.W. and Mitchell, D.R., 3rd edition, Chap. 17, 1968.

These authors list the disadvantages of using waters charged with solids as follows: (1) they cause wear, chiefly of pumps and cyclones by erosion, (2) they alter the density of the bath and increase viscosity of heavy media used for separation, and (3) they do not rinse washed products properly. They refer to one operator that used lime to neutralize acid mine drainage for use in a preparation plant. Reference is made to the work of Zelders (ref. 1 this paper). Others have reported a decrease in hardness of the wash water and an increase in chloride, sulphate and conductivity during coal preparation.

26. Hiorns, F.J. "Wear measurement in size-reduction machinery". Chem. and Process Eng., 1:47-49, 1971.

Wear of size-reduction plant accounts for an appreciable part of comminution costs, especially when highly-abrasive or corrosive materials are being ground. There are a number of both laboratory and full-scale methods of measuring wear rate, including radiotracer methods, which are the most sensitive. These, and the relation of laboratory studies to full-scale tests, are discussed here.

The author stated that, "For the more severely abrasive or corrosive substances the effect shows itself not merely as a contribution to low efficiency, but as a substantial or even major part of the overall cost, a fall off in the effectiveness of machines as surfaces are degraded and worn away, and loss of production while parts are replaced". Several references are included.

27. Gamol'Skaya, Z.M., Guterman, V.M. and Didkovskaya, N.A. "Abrasion-corrosion wear of steels and cast irons in wet coals of various deposits". Trans. Inst. Vniptuglemash U.S.S.R., 17:1-37; 1972 (in Russian).

Translation not available.

28. Zimmerman, R.E. "Japan's swirl cyclone, a new approach to dense-media cleaning". World Coal, 5:22-24; 1975.

Built from a design opposite to the conventional cyclones this new coal cleaning device is capable of separating larger

sizes of coal both economically and efficiently. Ni-hard or other abrasion-resistant materials can be used in its construction to resist wear.

29. Van der Walt, P.J. and Venter, W.P. "The use of Norwalt and Dynawhirpool dense medium separators in coal preparation". Aust. Mining, 6:30-38; 1975.

A description of the Norwalt separator with either a bucket or a wheel elevator, and the steps taken to reduce wear in the machine are presented. The wear problems associated with cyclone separators are discussed. The new Dynawhirpool separator is described and the features which reduce the wear rate in it are discussed.

30. Schmidt, R.A. "Current trends in coal preparation". Coal Mining & Processing, 9:74-76; 1975.

This review of present-day mechanical cleaning and crushing and their relation to changing mining methods indicates that in the near future plants will be built based on innovative use of available technology with new technology introduced as it is demonstrated.

A comprehensive assessment of coal preparation technology is in progress by Gibbs and Hill, Inc. (a subsidiary of Dravo Corp.), under a contract from the Electric Power Research Institute. The work covers established and new methods to improve coal quality prior to its use in electric utility combustion or conversion units.

31. Groseclose, G.E. "The role of vibrating screens in modern coal preparation plants". Coal Age, 1:92-96; 1976.

Knowledgeable selection, operation and maintenance of screens can minimize downtime, reduce labour costs and hold down the cost of replacement decking. The details of screen functions at various stages of preparation are described. Manganese steel, AR steel, polyurethane, rubber and T304 stainless steel are the materials recommended for the various types of screening.

32. O'Brien, E.J. and Sharpeta, K.J. "Water-only cyclones: their function and performance". Coal Age, 81:1:110-114; 1976.

The authors state that, "The material of construction for the hydrocyclone is dependent upon the specific application. For coarse coal with a top size from 1/4 to 1 1/2 in., cast type 4 Ni-hard with a Brinell hardness of 575-625 or refrax are excellent materials of construction. For fines, all ceramic or rubber-lined cyclones are standard". Increasing inlet pressure can be used to increase capacity but is not an economical way because of the resultant increased wear.

33. "Modern design in equipment for today's coal preparation". Coal Age, 81:1:115-16; 123-6; 139; 1976. (anonymous).

The article gives a partial summary of some equipment presently available or soon to be upcoming, on a regular basis, for the many demands of coal preparation techniques. Some of the units available are updates of past models of machines that have served the industry for years, others are more recent developments. Crushers, rotary plow feeders, disk filters, dryers, dense-media static baths, flotation machines, screens, hydrostatic precipitators, retractable stacking spouts, thickeners, filter presses and centrifuges as well as plastic and rubber for lining the equipment are briefly described and the addresses of suppliers are given. Some materials of construction are mentioned.

34. Grimm, B.M. "Preparation plant corrosion costs". Paper presented at the Convention phase of the A.M.C. '76 Coal Show; Mining Congress Journal, 62:6:62; 1976.

Grimm asserted that corrosion has been a major problem at Inland's Mine No. 1 preparation plant since the plant went into operation in 1966. Water soluble chlorides was the principal agent causing the corrosion (3000 ppm). Other agents were sulfates, sulphides, carbonates, iron, sodium, calcium and magnesium. Stainless steel, wood, rubber and plastics are used to resist corrosion as well as water treatment. Treatments such as electrodialysis, reverse osmosis, ion exchange and distillation are too costly for application to coal processing. He stated that there are no quick simple answers to the control of corrosion in coal preparation plants.

35. "Synthetic pipe makes high marks with Peabody Coal". Coal Mining and Processing, 13:8:57; 1976.

Peabody Coal Co. reports excellent performance for 9000 ft of polyethylene industrial pipe. The ultra-high-density pipe is expected to provide a service life of three to four years without rotation compared with only 12 months for a steel line that is rotated quarterly. The pipe is used to transport slurries containing 15 to 35 per cent solids (clays, shale, ultrafine pyrite and coal). Similar pipe is being used to transport slurries in the preparation plants.

36. Panoiu, N., Biclesanu, D. and Craciuneanu, C. "Method for investigating the wear of the grinding parts of coal mills". Rev. Roum. Sci. Techn. - Electrotechn. et Energ., 22:2:277-287; 1977.

This paper describes a method for investigating the wear of grinding parts of coal mills by means of experimental tests. The experimental results are corrected and then the equations for the curves of wear variation are integrated.